Snowplow Relative Priority Preemption Report

City of St. Cloud
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CITY OF
ST.CLOUD
MINNESOTA

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By: Blake Redfield and Tom Zabinski

Preface. This report will demonstrate the efficiencies and potential safety benefits gained from utilizing GPS based relative priority preemption in snowplows. To the best of our knowledge as of this writing, this is the most extensive analysis for snowplow relative priority preemption both in quantities of data captured and the study longevity to date. This report will give a brief history of the project's inception, grants received for the project, data collection methods, locations of the test site, equipment utilized for the project and a final analysis of the data collected. This report will also detail some of the legal hurdles that had to be overcome to use the GPS based snowplow preemption system and some of the state statutes that will need to be changed for the system to become commonplace.

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Relative Priority Preemption Background

1.1 Background. In October of 2014, a new technology was introduced to the City of St. Cloud operations personnel and attendees of the Minnesota Fall Maintenance Expo that is hosted each year at the St. Cloud Public Works Facility. The new technology was called Relative Priority Preemption hereafter referred to as RPP. This technology provides an intermediate level of traffic signal preemption for service and maintenance vehicles that could benefit greatly by receiving quick responding green signal indications while yielding to high level emergency vehicles (i.e. police cars, fire trucks, ambulances). The idea of utilizing this new technology on snowplow trucks was quickly identified and embraced. However, there had been no significant implementation of this technology anywhere in the country on snowplows, so little was known on how well the technology would function or what efficiencies and safety benefits might be gained by its use.

1.2 Traffic Signal Preemption Background. Traffic signal preemption is nothing new and was actually developed back in the 1970's. Most systems consist of an optical receiver and optical transmitter where a vehicle is equipped with an optical strobe light transmitter and the traffic signal system is equipped with optical receiving equipment. Out of the optical preemption systems came two different levels of use commonly known as "high priority" and "low priority". High priority preemption is what is used on police cars, fire trucks and ambulances and low priority is typically used on mass transit buses. High priority systems operate on the basis that opposing phases are quickly cleared and the green light becomes available to the emergency vehicle by the time it reaches the intersection. Low priority preemption used on mass transit buses is subtle in that it will typically extend a phase to allow a bus to catch the green light or reduce some time from opposing phases to allow the green light to come up a little sooner than it normally would. Both systems work well for their intended purposes.

1.3 The Preemption Dilemma. While there were many satisfied users of the traffic signal preemption systems, there were others that felt utilizing preemption would aid in other maintenance operations such as plowing snow or pavement marking painting. Some felt that high priority would be acceptable on maintenance vehicles but there becomes the issue of possible conflicts with emergency vehicles coming from an opposing direction. Others looked at low priority preemption. However, low priority responds slowly for a vehicle and does not guarantee a green traffic signal indication by the time a maintenance vehicle would reach the intersection.

1.4 Relative Priority Preemption (RPP). Relative priority preemption finally offered the efficiencies and safety features not previously available on either high or low priority preemption for road maintenance equipment. There were also some major equipment and software design differences in this new technology. The RPP system is a GPS (global positioning system) radio activated system allowing much better traffic signal responses compared to optical preemption systems. Since each vehicle equipped with GPS preemption equipment is transmitting its GPS coordinates to the traffic signal system, the traffic signal system can respond in a much more precise manner than with an optical system. The blend of radio and GPS also allows the traffic signal system to recognize the approaching vehicle on approaches with curves, hills, trees or other obstructions that hinder the operation of optical preemption systems. An additional feature of GPS based RPP is the ability for the traffic signal to know the projected route of the approaching vehicle by integrating the turn indicators of the vehicle with the GPS preemption equipment and respond accordingly, especially in a left turn maneuver.

The greatest safety feature for both maintenance vehicles and emergency vehicles with RPP is the ability of an emergency vehicle to override the request for the green indication of the maintenance vehicle. During normal maintenance operations, the RPP provides the quick response as high priority emergency equipment, while yet yielding to an emergency vehicle.

Pilot Project

2.1 Test Pilot Project Interest. After the demonstration of the RPP system at the 2014 Minnesota Fall Maintenance Expo, the City of St. Cloud was interested in doing a test site for the new technology. The pilot project would involve a small group of traffic signals along a roadway corridor and equip a small fleet of snowplows with the GPS based preemption equipment. Working with the Minnesota Local Road Research Board (LRRB), a request for a small grant was generated for seed money to assist in funding a pilot project. Upon receiving the small seed money grant, a small-scale project was developed with the requirement that the City of St. Cloud would report its findings after a period of testing.

2.2 Test Pilot Location. Several locations were reviewed in the St. Cloud area to determine what would be a good corridor with traffic signals at regularly spaced intervals and where multiple snowplows were required to plow the corridor. It was decided that CSAH 75 (Roosevelt Road) from 33rd Avenue to 22nd Street South in St. Cloud would be a good location for the test site. There are seven signalized intersections on this two-mile segment of roadway with two travel lanes in each direction and intersections having left turn pockets. Speed limits for this corridor are 40 MPH which also makes it somewhat safer for snowplow operation during the test.

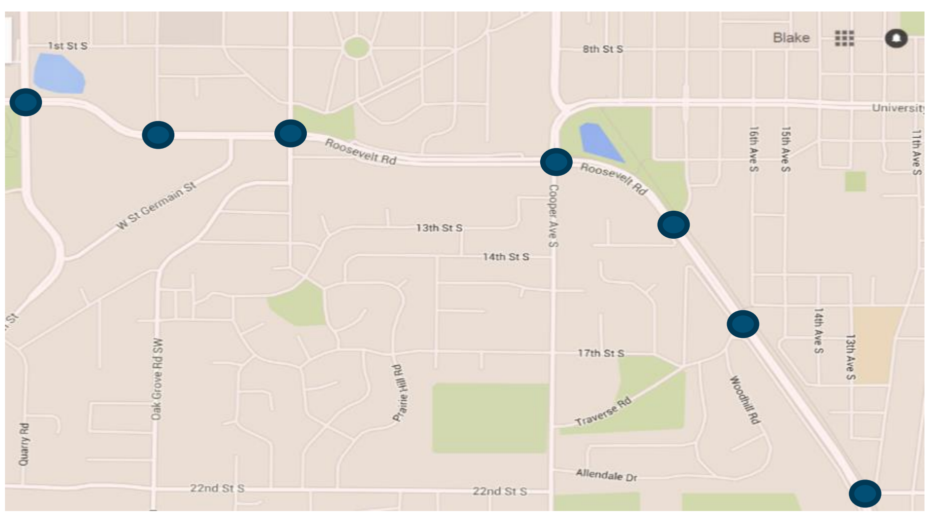


Figure 1: Test site corridor – CSAH 75 (Roosevelt Road)

2.3 Traffic Signal Equipment. Additional equipment was added to each of the traffic signal cabinets along the test site corridor. The equipment included a new GPS radio antenna unit attached to the traffic signal pole or cabinet and a new phase selector card that was installed in the cabinet's card rack.

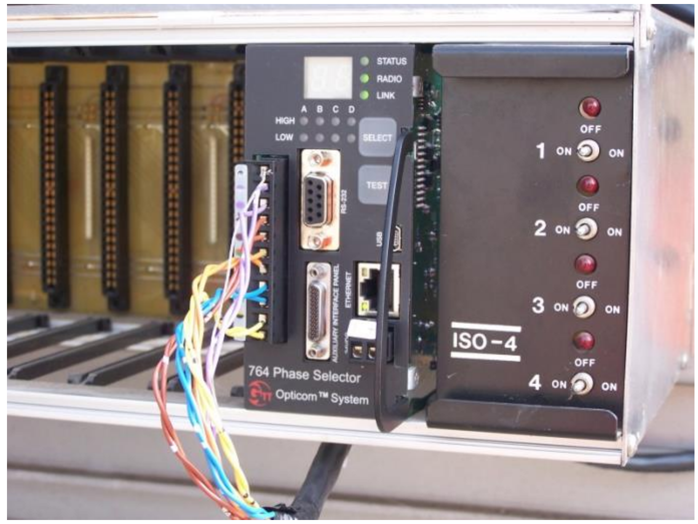


Figure 2: GPS Phase selector card installed in cabinet

Figure 3: GPS radio antennas attached to cabinet

Since the traffic signal would also be using the standard preemption system, the cabinets would be operating parallel systems as shown in figure 4.

Figure 4: GPS and optical preemption devices on traffic signal arm

2.4 Snowplow Truck Equipment. Four snowplow trucks that normally plow the test corridor were equipped with the GPS RPP system. The truck preemption system feeds vehicle proximity information to the traffic signals to preempt the traffic signal controllers allowing the entire group of four snowplows to pass through the signalized intersection on green signal light indications.

There were three different components that were installed on each of the snowplows for this test project. The first is a small dome-shaped antenna that was placed on the roof of the truck cab to receive satellite GPS signals and to communicate the vehicle's location to the signalized intersection. See figure 5.

Figure 5: GPS receiver and communicator antenna

Figure 6: GPS preemption unit and control panel

The second piece of equipment is the GPS preemption unit and control panel that allows the operator to turn the GPS preemption system off and on. A small cable runs between the antenna and the control panel. See figure 6.

The third and final piece of equipment is not actually part of the GPS RPP system but rather a means of tracking the location of the snowplow each time the preemption system is used. The piece of equipment is a GPS based dash camera that not only provides video with time stamps for future data recording but also shows the GPS position of the truck. See figure 7.

Figure 7: GPS dash camera for recording snowplow runs

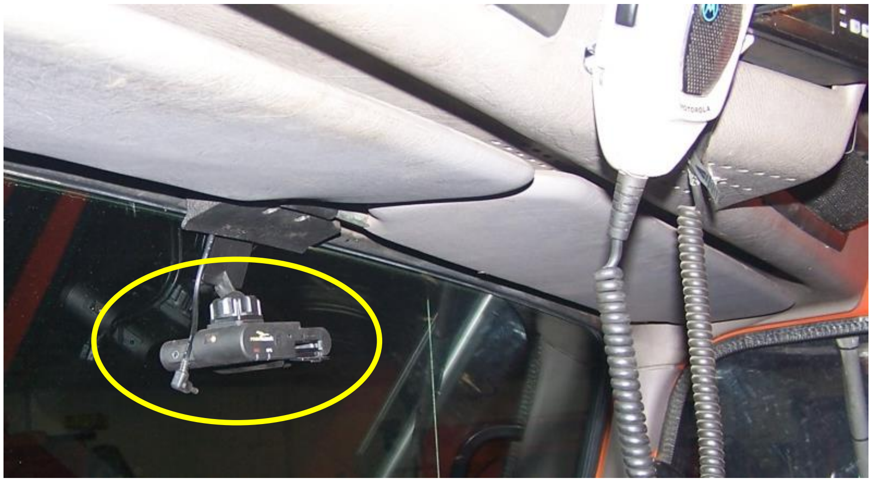


Figure 8: Sample of GPS dash camera playback with date and timestamp. The preemption received indicator light has also been circled.

Figure 8 shows a typical recording of the snowplows as they traversed the signalized corridor with the RPP in operation. With the video timestamps it was then possible to later record the data from each snowplow and determine travel times of each of the snowplow units.

Note: Throughout this study, all travel times are calculated for the completion of the route in the total of both directions of travel.

2.5 Permission by the Commissioner of Public Safety. Before this study could even commence, the City of St. Cloud was required to get permission from the State Commissioner of Public Safety for a "Traffic Signal Override" device to be used with the snowplows. (Minnesota Statute 169.06, Subd. 5b) This took a considerable amount of time as each truck operator had to be cleared for the project, each intersection had to be identified and each truck involved with the operation was recorded with the state. The state also required the City of St. Cloud to meet specific liability insurance requirements.

The Study

3.1 Study and Data Compilation Methodology. The basic structure of the study was to record data, compile data and then analyze data. This is typical of most studies. However, this study also required the recording of weather data from an outside source parallel with the time-period of each snowplow run. NOAA (National Oceanic and Atmospheric Administration) weather was recorded for each snow event along with the travel time data.

It was noted from the beginning of the study that a baseline for final analysis was required to compare data using the RPP equipment with data not using the RPP equipment. To meet this requirement, during many of the snow events the RPP equipment was **not** used to develop a baseline for comparisons.
(Note: Due to the effectiveness of the RPP, it was difficult to not have the operators utilize the equipment during a snow event. Because of this, the study is somewhat short on baseline data which will be noted later in this report.)

Back at the office, the travel time video data were analyzed from each snowplow equipped with the RPP system. The time of day was recorded into a spreadsheet when each truck was in the center of each signalized intersection along the study corridor. These data were broken down by east and west travel directions. Travel times were then calculated for each truck between each signalized intersection, for the length of the route and then the total time for both travel directions along the plowing route. (Note: In this portion of the data compilation minutes and seconds are used for time units. In the final data analysis, decimal minutes are used.)

Event 180331	#114	Minutes	#127	Minutes	#126	Minutes	#141	Minutes
22nd St. S	5:04:35		5:04:42		5:04:55		5:04:50	
Traverse Rd.	5:06:33	0:01:58	5:06:38	0:01:56	5:06:46	0:01:51	5:06:43	0:01:53
Washington Memorial Dr.	5:07:38	0:01:05	5:07:43	0:01:05	5:07:51	0:01:05	5:07:47	0:01:04
Cooper Ave. S	5:08:48	0:01:10	5:08:53	0:01:10	5:09:01	0:01:10	5:08:57	0:01:10
25th Ave. S	5:10:43	0:01:55	5:10:48	0:01:55	5:10:56	0:01:55	5:10:51	0:01:54
29th Ave. S	5:11:41	0:00:58	5:11:47	0:00:59	5:11:54	0:00:58	5:11:50	0:00:59
33rd Ave. S	5:12:59	0:01:18	5:13:04	0:01:17	5:13:13	0:01:19	5:13:09	0:01:19
West Bound Total		**08:24.0**		**08:22.0**		**08:18.0**		**08:19.0**
TH 15	5:38:24		5:38:27		5:38:31		5:38:36	
33rd Ave. S	5:39:50	0:01:26	5:39:55	0:01:28	5:39:59	0:01:28	5:40:02	0:01:26
29th Ave. S	5:41:57	0:02:07	5:42:03	0:02:08	5:43:31	0:03:32	5:43:37	0:03:35
25th Ave. S	5:44:27	0:02:30	5:44:30	0:02:27	5:44:36	0:01:05	5:44:40	0:01:03
Cooper Ave. S	5:46:37	0:02:10	5:46:42	0:02:12	5:46:46	0:02:10	5:46:51	0:02:11
Washington Memorial Dr.	5:47:42	0:01:05	5:47:46	0:01:04	5:47:50	0:01:04	5:47:54	0:01:03
Traverse Rd.	5:48:45	0:01:03	5:48:49	0:01:03	5:48:54	0:01:04	5:48:58	0:01:04
22nd St. S	5:50:23	0:01:38	5:48:49	0:00:00	5:50:27	0:01:33	5:50:30	0:01:32
East Bound Total		**11:59.0**		**10:22.0**		**11:56.0**		**11:54.0**

Figure 9: Sample of compiled travel time data. Note uniform travel times for each vehicle when utilizing the relative priority preemption system.

NOAA weather data were also imported into a spreadsheet format to keep the data uniform. Figure 10 shows the typical weather data that would later be used for the final analysis on the effectiveness of the relative priority preemption equipment. Weather data will be noted later in this report. Some of the variables considered with the weather data were temperature, hourly snow rates and total snow fall for the event. (Note the event number represents the year, month and day).

The final data analysis included reviewing the various data sets and trying to make relevant and meaningful conclusions. The data included 73 different snow events from 2015 -2020, weather data for these events and some incomplete data sets that would require special attention. Some of the complications to the travel data included snowplows that were not available for the route, a snowplow that would be asked to pull off the route and work in another area, construction that occurred at the 33rd Avenue signalized intersection that removed the RPP equipment for a period of time during the study and other minor data glitches that would require additional scrutiny.

Event 180331

Date	Time (cdt)	Wind (mph)	Vis. (mi.)	Weather	Sky Cond.	Temperature (ºF) Air	Dwpt	6 hour Max.	6 hour Min.	Relative Humidity	Wind Chill (°F)	Heat Index (°F)	Pressure altimeter (in)	Pressure sea level (mb)	Precipitation (in.) 1 hr	3 hr	6 hr
31	10:53	NW 20 G 26	10	A Few Clouds	FEW017	19	8			62%	3	NA	30.1	1021.9			
31	9:53	N 20 G	10	Fair	CLR	18	9			68%	2	NA	30.08	1021.2			
31	8:53	N 18	10	Overcast	OVC090	18	12			77%	2	NA	30.04	1019.8			
31	7:53	N 17 G 24	9	Overcast	FEW019 BKN060 OVC070	18	13			81%	3	NA	30	1018.4			
31	6:53	N 14 G 24	10	Overcast	BKN017 OVC036	22	18	26	22	85%	9	NA	29.93	1016			0.35
31	5:53	N 15 G 26	10	Overcast	SCT014 OVC045	23	20			88%	10	NA	29.87	1013.7			
31	4:53	NA	1.75	Light Snow Fog/Mis	BKN010 OVC032	24	22			91%	NA	NA	29.82	1012.1	0.11		
31	3:53	N 12 G 22	0.25	Snow Freezing Fog	VV005	25	23			92%	14	NA	29.81	1011.5	0.12	0.24	
31	2:53	NE 13 G 22	0.5	Snow Freezing Fog	BKN008 OVC014	25	24			96%	13	NA	29.8	1011.2	0.07		
31	1:53	NE 16 G 24	1.25	Light Snow Fog/Mis	FEW008 OVC015	26	24			92%	14	NA	29.81	1011.6	0.05		
31	0:53	E 8	0.25	Heavy Snow Freezing Fog	VV006	26	25	30	26	96%	18	NA	29.87	1013.8	0.11		0.13
30	23:53	E 9	1.5	Light Snow Fog/Mis	OVC018	26	24			92%	17	NA	29.91	1015.2	0.02		
30	22:53	SE 8	6	Light Snow	BKN034 OVC075	28	21			75%	20	NA	29.97	1017.1			
30	21:53	E 7	10	Overcast	OVC050	29	21			72%	22	NA	30.01	1018.5			
30	20:53	NE 5	10	Overcast	BKN060 OVC085	29	21			72%	24	NA	30.03	1019.2			
30	19:53	NE 3	10	Overcast	OVC100	29	21			72%	NA	NA	30.05	1019.9			
30	18:53	NE 5	10	Mostly Cloudy	BKN110	30	21	33	27	69%	25	NA	30.06	1020.2			
30	17:53	NE 3	10	Partly Cloudy	SCT031	31	21			67%	NA	NA	30.07	1020.6			

Figure 10: Sample of compiled weather data from NOAA

3.2 Preliminary Analysis. After the first year of using the relative priority preemption system on the four snowplows, St. Cloud Traffic Services did some basic analysis primarily on the time efficiencies gained by use of the new technology. There were no considerations made on snow types or amounts. Preliminary analysis showed a 25-30% improvement in reduced snow plowing times.

3.3 Final Data Analysis. Due to the amount and types of various data sets after five years of data collection, it was decided to bring in an outside group that could both help with the final data analysis and provide an unbiased synopsis of the project. The St. Cloud State University Statistics Department was hired for this important final aspect of the project. The team consisted of three graduate level statistics students and their advising professor. There were two main objectives asked of the statistics group. First, determine the time efficiencies gained through data analysis. Second, determine if a model could be developed to predict efficiencies gained utilizing this new technology. This final document report by St. Cloud State is *The Effects of Opticom™ on Snowplow Efficiency*[1] hereafter referred to as "*TEOSE*".

The final analysis began in early fall of 2019 and continued into February of 2020. As there were a couple of snow events in late 2019 and early 2020, the additional data were added into *TEOSE*.

Study Findings

4.1 Data Requirements. After turning the snowplow data over to the St. Cloud State Statistics group, it was noted that the five-year study data was short on snowplow runs that were not using the RPP system to establish a baseline. To make up for this, city snowplow drivers simulated several runs without using the preemption system to fill in some of the data gaps. These runs would be replaced if there were enough similar runs once snow began in the fall of 2019. The dry run data allowed the statistics group to set up their analysis methods and begin their analysis. (Note: Some of the dry runs were replaced with actual snowplow run data.) In total, there were 73 runs that were used for the snowplow preemption analysis.

4.2 Analysis Methodology. Due to the amount of data that had been compiled, both standardized and specialized statistical methodologies were utilized to analyze the snowplow preemption data. "*Data was compiled in Excel and statistical analyses were performed using R[2], and JMP[3]. A t-test provided statistically significant evidence that using the RPP technology decreased the amount of time required to complete the route. T-tests were also run on three other two-level variables - whether the route was plowed in daylight or at nighttime, on weekends or weekdays, and whether there was intersection construction on the route. Only the t-test on route time grouped by intersection construction provided evidence of a difference in the average time taken to clear the route. One-way ANOVA[4] showed that there was a statistically significant difference in the average times of the snow amount categories. Though the tests showed that there is a statistically significant difference in route time when RPP is used and a predictive model was built, lack of data proved to cause difficulties in much of the analysis, leading to simplification of several variables."*[5] The previous citation being a summary of both the analysis and findings, the analysis does show some lacking in baseline data. However, the data is still conclusive in determining definite efficiency improvements utilizing the snowplow relative priority preemption.

4.3 Analysis Variables. At the onset of the study, the City of St. Cloud was expecting to show travel time improvements for the snowplows with several variables including time of day, snow amount totals, day of week, route direction and others. However, even with the amount of data that had been collected over this five-year study, it was found that several of the time-period variables had to be combined to become viable. Eventually, the variables were reduced to days or nights, weekday or weekend, and three different snow total groups.

4.4 Data Deficiencies / Inconsistencies. Analysis was completed on some of the data deficiencies / inconsistencies during the study period. One of these deficiencies was the effect to the travel time if one of the snow-plows was not being used for a run. Another was the effect of one of the traffic signal intersections undergoing reconstruction during the study period. Statistical t-tests and One-Way ANOVAs were exercised to determine if there was an overall impact on the data due to these inconsistencies.

Tables Showing Variation with Missing Snowplow Trucks[6]

Average Time With No Trucks Missing	Average Time With Trucks Missing	Average Time Difference	Lower 95%	Upper 95%	P-value
7.39	7.42	0.03	-0.57	0.51	0.91

Table 1: The results of the westbound t-test, which include the average times (in minutes, mm.xx) for each group, the average time difference between the groups, the 95% confidence interval, and the p-value.

Average Time With No Trucks Missing	Average Time With Trucks Missing	Average Time Difference	Lower 95%	Upper 95%	P-value
8.13	8.49	0.36	-1.02	0.31	0.28

Table 2: The results of the eastbound t-test, which include the average times (in minutes, mm.xx) for each group, the average time difference between the groups, the 95% confidence interval, and the p-value.

4.5 The Effects of Missing Trucks. The two tables above indicate that there was very little difference in time with a missing snowplow truck on a standard run. This factor simplified the overall evaluation of the study as there were several trips made without the full group of four snowplows.

4.6 The Effects of Traffic Signal Construction at one of the signals within the Study Group. Construction at one signalized intersection did have a definite impact on travel times for the snowplows. Statistical testing was completed on several variables with the signal construction including time of day, day of week and snowfall amounts. Each of these variables provided varying outcomes and were defined in the *TEOSE*[7] study.

4.7 Time of Day. As noted earlier in this report, time of day was reduced to "day" and "night", "weekday" and "weekend" as there is not enough snowplow run data to be broken down any further and have any statistical significance. The first group that will be reviewed is "Time of Day including the Events During Construction".

Table 3: Number of Runs by *Time of Day* Including Data During Traffic Signal Construction

	Non-RPP	RPP
Day	6	27
Night	7	33

Table 6 of TEOSE[8]

4.8 *Time of Day* Including Data during Traffic Signal Construction. There are more total number of runs when the data is included utilizing the signal construction period. However, this data does tend to skew the final analysis somewhat and is probably not as good as the next section that will exclude the data during the traffic signal construction. The table below shows the run times by "Day" and "Night" and the use or non-use of RPP.

Table 4: Run Times by *Time of Day* Including Data during Traffic Signal Construction (mm.xx)

	Non-RPP Run Time	RPP Run Time	Run Time Delta	Run Time Reduction Percent Change
Day	19.89	14.62	5.27	26.5%
Night	18.76	15.35	3.41	18.2%
Delta	1.13	.73		
Percent Change	5.7%	4.8%		

Statistics derived from Table 7 of TEOSE[9]

As this is the overall data from the study, it is interesting to note a couple of things from the table above. First, the night runs when **not** utilizing the RPP require less time than those during the day. This is more than likely due to lower traffic volumes at night and the main line roadway having more traffic signal "green time" than during the day. The second point of interest is that there is a substantially improved time reduction when utilizing the RPP during the day compared with the night use. It should also be noted that because the one traffic signal RPP system was not functional for part of this study, the time reductions should be less than for the data set without the construction time period.

4.9 *Time of Day* Excluding Data during Traffic Signal Construction. Since the previous section included all data throughout the duration of the study, the data set for the period excluding the traffic signal construction time period will be smaller. The data set may be smaller, but shows improved time reductions for both night and daytime use of the fully functional RPP system.

Table 5: Number of Runs by *Time of Day* Excluding Data during Traffic Signal Construction

	Non-RPP	RPP
Day	5	20
Night	6	20

Table 8 of TEOSE[10]

Table 6: Run Times by *Time of Day* Excluding Data during Traffic Signal Construction (mm.xx)

	Non-RPP Run Time	RPP Run Time	Run Time Delta	Run Time Reduction Percent Change
Day	19.83	14.11	5.71	28.8%
Night	18.91	14.89	4.02	21.3%
Delta	.92	.78		
Percent Change	4.5%	5.2%		

Statistics derived from Table 9 of TEOSE[11]

This data shows the system in operation during two different times of the days and that there are significant improvements in travel times during each. This represents a better data set than the previous as it shows the entire preemption system functioning properly. The “day” period reduction is significant with a 28.8% travel time reduction. The “night” period shows less percentage improvement but is almost 5% less travel time to begin with without the use of the preemption system.

4.10 Day of Week. At the onset of the project there was an interest if the data would indicate any significant travel time differences for snowplows based on the day of the week. However, data was limited, especially for “non-preemption” events and it became difficult to determine any statistical significance based on day of week. To improve the number of events, the data sets were reduced to “weekday” and “weekend”. The events were reduced as per the table below.

Table 7: Number of Runs by *Day of Week* <u>Including</u> Data during Traffic Signal Construction

	Non-RPP	RPP
Weekday	9	45
Weekend	4	15

Table 11 of TEOSE[12]

It should be noted that there are significantly more data sets for the “weekday” category than the “weekend” category. However, there are only two days during the weekend and five days for the week thus the imbalance is somewhat offset because of this factor. As with the “time of day” analysis, the traffic signal construction period when the RPP was not functional was used as a data factor.

Table 8: Run Times by *Day of Week* <u>Including</u> Data during Traffic Signal Construction (mm.xx)

	Non-RPP Run Time	RPP Run Time	Run Time Delta	Run Time Reduction Percent Change
Weekday	19.12	14.95	4.17	21.8%
Weekend	19.63	15.22	4.41	22.5%
Delta	.53	.27		
Percent Change	2.6%	1.8%		

Statistics derived from Table 12 of TEOSE[13]

The conclusion from this statistical exercise is that there was very little difference in snowplow run times based on the weekdays versus weekends with both categories “Non-RPP” and “RPP” showing less than a 3 percent change in time. As with “time of day” there was a significant and quite consistent improvement in reduced snowplow travel times utilizing RPP averaging just over 22 percent.

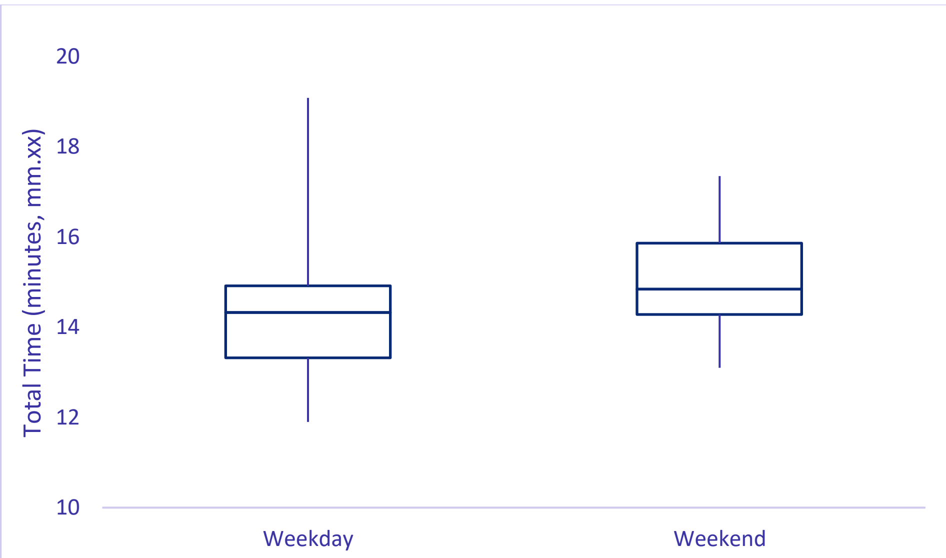
Table 9: Number of Runs by *Day of Week* Excluding Data during Traffic Signal Construction

	Non-RPP	RPP
Weekday	7	28
Weekend	4	12

Table 13 of TEOSE[14]

The number of runs does drop off substantially for the "RPP" category. Fortunately, the "Non-RPP" category providing the baseline is not reduced much when compared to the *Day of Week* Including Data during Traffic Signal Construction. To this point in this report there has not been much need for statistical box charts. However, the box chart does help visualize the variance in the data found in this data set for weekdays.

Day of Week Excluding Data during Traffic Signal Construction, Box Chart 1



Box Chart showing variation in the weekday data set by the extended tail length on the top side of the right-hand boxes. TEOSE Graph 4[15]

Table 10: Run Times by *Day of Week* Excluding Data during Traffic Signal Construction (mm.xx)

	Non-RPP Run Time	RPP Run Time	Run Time Delta	Run Time Reduction Percent Change
Weekday	19.16	14.31	4.85	25.3%
Weekend	19.63	14.94	4.69	23.9%
Delta	.47	.63		
Percent Change	2.4%	4.2%		

Statistics derived from Table 14 of TEOSE[16]

After reviewing the *Day of Week* data with excluded data during the traffic signal reconstruction, even though this is a small data sample and with some degree of variation, a 24 – 25% reduction in travel time for snowplows should be expected during these time periods. As with the other variables reviewed to this point, all situations have shown high teens to mid-20's percent travel time improvements for snowplows using the RPP.

4.11. The Effects of Snow Variations on Snowplow Travel Times. Several variables including total snow accumulations, air temperature, moisture content of the snow, rate of snowfall and others were reviewed to determine a relevant correlation between weather and snowplow travel times. As with many studies it was quickly determined that there was a great deal of weather data that would have to be condensed for use. The final consensus was to create three categories for snow totals: low, less than 1 inch of snow; moderate, between 1.0 and 3.5 inches; and high, greater than 3.5 inches. Snow amounts were based on the daily accumulation, not the entire accumulation if the snow occurred over multiple days. Further analysis for other factors could be done in the future.

Table 11: Number of Runs *Snow Rates* Including Data during Traffic Signal Construction

	Non-RPP	RPP
Low <1 inch	5	19
Moderate 1 – 3.5 inches	7	30
High > 3.5 inches	1	11

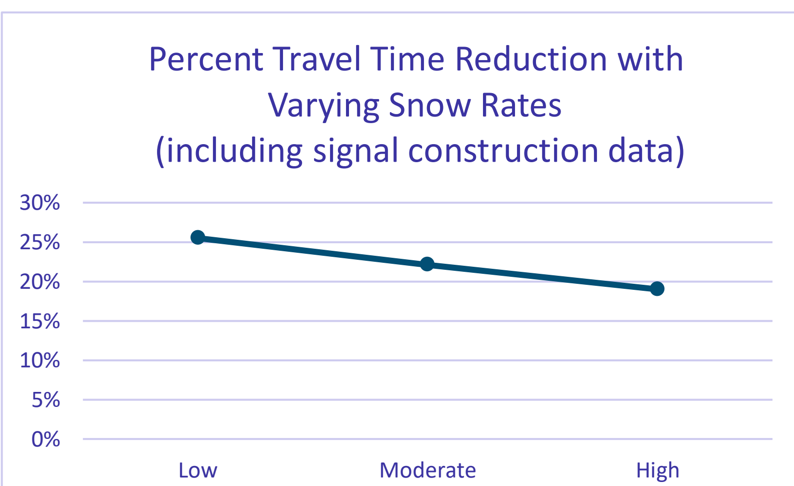
Table 15 of TEOSE[17]

Table 12: Run Times with Various Snow Rates Including Data during Traffic Signal Construction (mm.xx)

	Non-RPP Run Time	RPP Run Time	Run Time Delta	Percent Run Time Reduction
Low [A]	18.71	13.94	4.77	25.5%
Moderate [B]	19.52	15.2	4.32	22.1%
High[C]	20.45	16.42	4.03	19.7%
Δ B->A	0.81	1.26		
Δ C->B	0.93	1.22		
Δ C->A	1.74	2.48		
%Δ B->A	4.1%	8.3%		
%Δ C->B	4.5%	7.4%		
%Δ C->A	8.5%	15.1%		

Statistics derived from Table 16 of TEOSE[18]

Snow Rates, Chart 2



From this data and analysis it has been demonstrated that there is an effect on travel times using the RPP based on snow amounts. The greatest improvement when using the RPP was during low snowfall amounts and is virtually linear in performance attenuation as snow amounts become greater. (It should be noted that there was limited data for non-RPP use during heavy snow amounts.)

The second condition in which the snowfall amounts data were analyzed was excluding data during the traffic signal construction.

Table 11: Number of Runs *Snow Rates* Excluding Data during Traffic Signal Construction

	Non-RPP	RPP
Low <1 inch	5	15
Moderate 1 – 3.5 inches	5	19
High > 3.5 inches	1	16

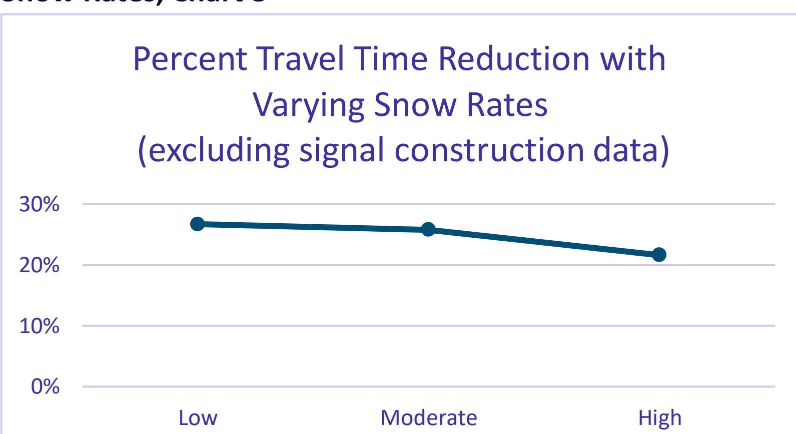
Table 17 of TEOSE[19]

Table 12: Run Times with Various Snow Rates Excluding Data during Traffic Signal Construction (mm.xx)

	Non-RPP Run Time	RPP Run Time	Run Time Delta	Percent Run Time Reduction
Low [A]	18.71	13.71	5	26.7%
Moderate [B]	19.73	14.64	5.09	25.8%
High[C]	20.45	16.03	4.42	21.6%
Δ B->A	1.02	0.93		
Δ C->B	0.72	1.39		
Δ C->A	1.74	2.32		
%Δ B->A	5.2%	6.4%		
%Δ C->B	3.5%	8.7%		
%Δ C->A	8.5%	14.5%		

Statistics derived from Table 18 of TEOSE[20]

Snow Rates, Chart 3



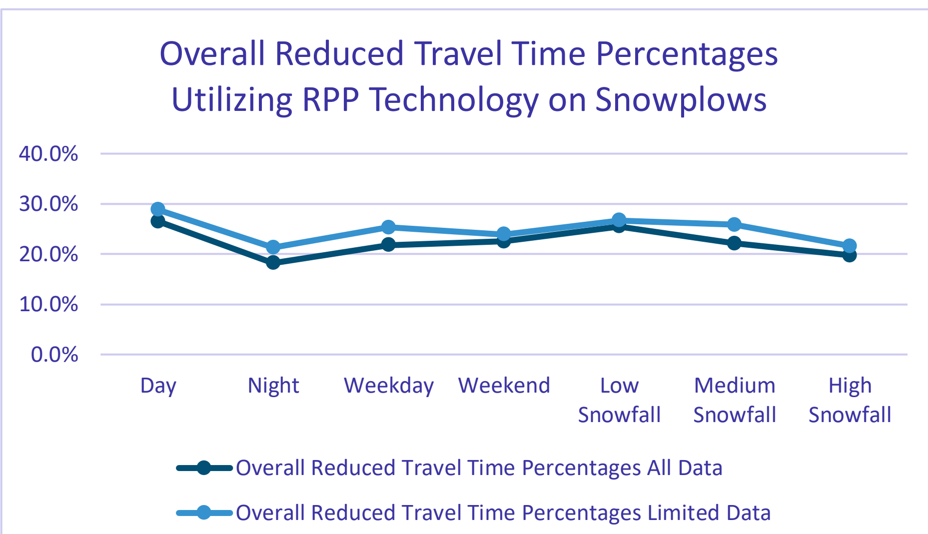
As with previous statistical variables, the data is "better" as it excludes the time period when the traffic signal was being reconstructed while at the same time has less data points. However, there is an even higher performance improvement with this data set than the previous showing a 26.7% performance improvement in light snow. The linearity is somewhat less with this data set than the previous, but again demonstrates attenuated RPP performance as snow amounts increase. (It should be noted that there was limited data for non-RPP use during heavy snow amounts.)

4.12 Summarized Effects of RPP on Snowplow Route Times. There were two primary dependent variables that were being tested in this study: travel times utilizing the RPP technology and travel times not utilizing the RPP technology. Both variables were subjected to independent variable testing by varying snowfall amounts under two scenarios: using data that occurred during the traffic signal construction and using data that occurred outside the period of the traffic signal construction. Correlations and trends were also reviewed for day vs. night, weekday vs. weekend and snow amounts while analyzing all factors with data that occurs during the entirety of the study compared with data that was compiled outside the traffic signal construction project.

The primary shortcoming of this study was the lack of data when not using RPP during snowplowing events. Due to this, the calculated 20 percent margin of error is higher than what should be seen on this type of study. However, it was obvious with the data that there were reduced snowplow travel times in every tested scenario. The average statistical travel time improvement for snowplows utilizing the RPP technology for this study is 22 percent. To obtain a 95 percent confidence level for improved travel time utilizing RPP, the statistical range is 2 percent to 42 percent travel time reduction.

By compiling the data from the previous variables and scenarios, the chart below indicates how each of these variables if affected using the RPP technology. It is interesting to note that both data sets track quite closely, with and without the data used during the traffic signal construction.

Overall Reduced Travel Time Percentages, Chart 4



Predictive Model

5.0 Predictive Model. The final portion of the study conducted by the SCSU statistics group was to develop a predictive model utilizing the Relative Priority Preemption technology on a snowplow. The model formulated works quite well. However, it is exclusive to this study, to the route and to the construction that occurred during the study. Utilizing the basics of their predictive model methodology, a more universal model could be developed but is beyond the scope of this report. Some of the variables to be considered will be route lengths, number of traffic signals, number of traffic lanes, normal snow plowing speeds, roadway geometrics, traffic volumes, snow amounts, time of day, day of week and many other roadway related variables.

Study Summary

6.0 Study Summary. This study is significant in that it does show the effectiveness of the RPP technology for snowplows for a local road agency. But the benefits of RPP go beyond the improved efficiencies presented in this document. There are many safety benefits and operational benefits that are difficult to calculate. Keeping snowplows in a platoon allows each snowplow to traverse through the intersections keeping other vehicles out of the snowplow group. It also reduces the problems of unplowed snow windrows in the middle of the roadway that cross traffic at an intersection may have difficulties traversing. Heavy snows can cause stopped snowplows to stall at an intersection requiring them to back up (not a safe maneuver) to get moving again. Reduced snow plowing times also clears the road for emergency vehicles when they are critically needed.

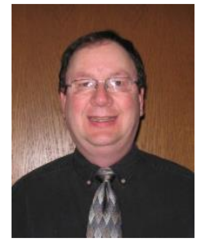
The GPS portion of the Relative Priority Preemption is a great improvement over its 1970's optical technology predecessor with much more precise signal integration and accuracy. Relative Priority Preemption has a great future for the roadway maintenance world and should become part of the traffic signal infrastructure for every agency that operates traffic signals.

Future of Relative Priority Preemption

7.0 Future of Relative Priority Preemption. There are really three major factors that need to occur in the realm of RPP. First, the units must become the next device in the evolution of traffic control devices and replace outdated high and low priority optical equipment that has been around for decades. Second, state and local statutes will need to be updated to allow for the use of RPP for maintenance equipment. Third, the use of the RPP devices must be regulated in a reasonable manner to protect the public and government agencies. Training and certification should be required for anyone who will be using these devices.

Thank You. A word of thanks on this project to the LRRB for providing the City of St. Cloud with a small grant to get this pilot project started. Another word of thanks to the St. Cloud snowplow drivers who participated in this project and who were so diligent in getting their travel time data recorded. And finally, a special thanks to the Saint Cloud State University Statistics Department for their efforts on analyzing a tremendous amount of unusual data in the form of video, weather information and snowplow travel time data.

About the Authors.



Blake Redfield is the Traffic Systems Manager for the City of St. Cloud, Minnesota. Blake comes from a traffic engineering and electrical engineering background and has been involved with transportation engineering and operations since 1986. Blake has a diverse educational background from several colleges and universities in the upper mid-west. Blake's primary role in this study was setting up the test data collection methods and traffic signal preemption equipment.

Tom Zabinski CM, is the Operations Manager, City of St. Cloud, Minnesota. Tom's education includes an AAS Degree in Supervisory Management from Dakota County Technical College and is a CM (Certified Manager) from the Institute of Certified Professional Managers through James Madison University, Harrisonburg, Virginia. Tom also has thirty-five years of experience in the maintenance of roads including snow and ice control. Tom started his career plowing snow and mitigating ice using a variety of equipment. Tom became a Maintenance Supervisor for the City of St. Cloud in 2012 and is currently serving as Operations Manager for the City of St. Cloud. Tom manages a staff of up to 28 professional maintenance operators conducting snow and ice control on 766 lane miles of road, 248 cul-de-sacs, and 42 miles of alleys. Tom's primary role in this study was data collection and keeping the project on-track with its initial goals.

Citations

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